WELL PREPARATION – EXISTING WELLS

Often the investigation of a water supply system contaminated with coliform bacteria will show that coliform bacteria are coming directly from the well. In these cases, the water well needs to be disinfected. However, the well must be properly prepared before disinfection. Debris in the bottom of the well, scale on the sidewalls of the casing, and slime buildup from biofouling organisms can interfere with the effective disinfection of the well. Barriers such as mineral scale or biofilm can limit the ability of chlorine to penetrate such barriers and reach the sheltered organisms, regardless of the concentration of hypochlorous acid or hypochlorite ion (Coombs, 2001).

Existing Well Construction Deficiencies or Problems
Evaluation of the sanitary integrity of the water well should be done before any attempt is made to disinfect the water supply system. The deficiencies or problems that may lead to contamination of the well include, but are not limited to:

1. **Buried Wellhead.** Buried wellheads are typically equipped with a compression-type well seal. Over time the gaskets in the seals begin to leak and contaminated water from near the ground surface can enter the well. In addition, the well is not easily accessible for repair. When the wellhead is exposed for any purpose, the casing should be extended to at least 12 inches above grade, and the wellhead equipped with an approved well seal or cap and a pitless adapter provided.

Buried well seal

2. **Unprotected Suction Line.** Any piece of pipe buried in the ground can develop leaks through mechanical damage or corrosion. A buried unprotected suction line from a well pump can allow contaminants to enter the water supply when the pump operates, sucking contaminants into the water supply. When an unprotected suction line is encountered, it should be replaced with a suction line that is protected with outer concentric piping. Converting jet pump systems to submersible pumps is also a means of eliminating buried suction lines.

Pumps with unprotected suction lines.

3. **Old Style or Damaged Well Cap**. Well caps that set on top of the casing and are secured by set screws or similar devices are generally not vermin-proof. Insects or other vermin may enter the well through the opening between the casing and the overlapping portion of the cap. Similarly, damaged well caps (such as those shown below) can allow rainwater, bird droppings, and other contaminants to enter the well casing. When damaged or older style well caps are encountered, they should be replaced with approved weather and vermin proof caps.

Damaged well caps

4. **Deteriorated or Damaged Casing.** Any opening in the casing caused by mechanical damage (e.g., hit by snow plow or other vehicle or damaged by vandalism) or corrosion may allow contaminants to enter the well. Damaged casing should be replaced, or the well should be properly plugged and a new well installed.

Cracked casing

Old dug well

5. **Unapproved Well Construction (less than 25 feet deep, crock well, short casing, etc.)** Any well that has been constructed in such a manner that contaminants from near the ground surface may enter the water supply should be plugged and replaced with a properly constructed well.

6. **Abandoned Wells on the Site.** Abandoned wells that have not been properly plugged provide a means for contaminants from near the ground surface to enter the ground water. An unplugged abandoned well can result in contamination of nearby water wells. Abandoned wells must be plugged using approved materials and methods.

Unplugged abandoned wells

7. **Openings in Electrical Appurtenances Such as Conduit or Junction Boxes.** Broken seals, unsecured conduit with ends exposed, or damaged electrical appurtenances provide access points for rain and/or insects to enter the water supply. These unprotected openings must be sealed when discovered.

Junction box on well cap and unsealed electrical conduit.

Yard hydrant – Potential cross connection

8. **Cross Connections with Contamination Sources** (such as an unapproved water supply tied in series with the well and stop and waste yard hydrants). Cross connections provide a means for the backflow or backsiphonage of contaminants into the water supply. Cross connections must be eliminated by installing approved cross connection control devices.

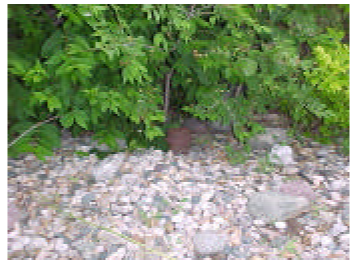
If well construction deficiencies are not corrected, treatment of the water well with chlorine may be a futile exercise, as the well may again become contaminated because of the defect.

Unapproved source of water.

Insect infested cap

Well Caps/Seals

If an old style well cap (not insect proof) is present or if the cap is damaged, insects may have entered the well and the bottom of the well may need to be flushed and disinfected. This condition is aggravated if the wellhead is surrounded by vegetation (bushes, tall plants, etc.), which attracts insects. Vegetation should be cleared away from the wellhead.



Old style cap located under a bush

Well Vents

Well caps or seals on a well equipped with a submersible pump are normally provided with a vent opening to allow the movement of air in and out of the casing as the well's water level fluctuates with pump operation. The vent helps prevent the formation of a partial vacuum inside the casing, which can enhance the potential for contaminant entry through leaking joints, corrosion formed holes in the casing wall, or other entry points (Joyce, 1982). If a well with a history of coliform bacteria contamination does not have a proper casing vent, one should be provided. A vent should be pointed downward, screened, and properly sized to allow sufficient air movement.

The movement of atmospheric air into the well is not normally considered a possible source of coliform bacteria contamination. However, the University of Wisconsin, in cooperation with the Wisconsin Department of Natural Resources, conducted a study (Trest, et al., 2001) investigating the possibility of air borne contaminants entering a well. The study suggested a possible link between air movement into a well casing and coliform bacteria contamination. The study concluded that conditions surrounding the wellhead location may play a role in whether coliform bacteria were detected in air samples. Conditions that influenced the likelihood of finding aerosolized coliform bacteria include:

- The presence of pet or fecal material close to the well
- Vegetation surrounding the wellhead.
- Recent lawn mowing around the well.
- During and within three hours after precipitation.

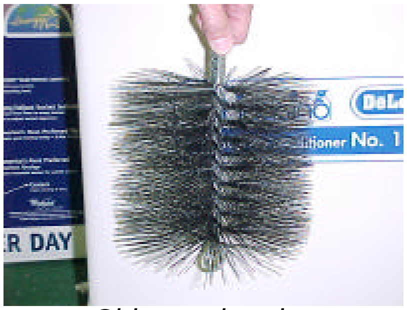
These conditions should be considered when trying to determine the source of a well's contamination.

Well Cleaning

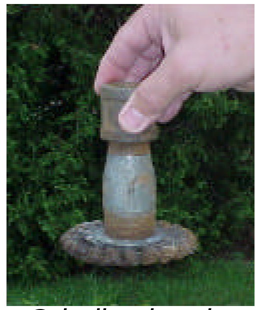
The accumulation of scale and other debris on the sidewalls of the casing or in the bottom of the screen/borehole may "use up" available chlorine or protect bacteria from exposure to a chlorine solution. In these cases, the well should be cleaned and flushed before starting the chemical treatment phase of the disinfection process. Cleaning of the well may include:

1. “Scrubbing” the sidewall of the casing with a swab, packer, brush, or similar device.

Typical packers and seals used to clean the inside surfaces of well casing.



Chimney brush



Grinding brush

Brush made from wire cable

Typical brushes used to scrub the inside surfaces of well casing.

2. Removing debris from the bottom of the screen/borehole with an air line, bailer, or other method.

3. Pumping the well to waste to remove suspended materials in the water is essential, since these suspended materials interfere with the effectiveness of the chlorine (LeChevallier, et al., 1981). The suspended materials can bind up with or use up available chlorine resulting in less chlorine being available for disinfection. The water well should be pumped until the water is clear. Lower the pump to as close to the bottom of the well as possible during the pumping period.

WELL FLUSHING

Flushing is the process of using the scouring action of moving water to help rid a water supply of contaminants. Flushing is an essential part of the disinfection process (Schnieders, 2001). Flushing normally takes place several times during the disinfection process.

- ✓ Flushing is a normal part of the development of a newly constructed well and the preparation of an existing well before chlorine treatment.
- ✓ Flushing a water supply after treatment with chlorine is required to remove the chlorine residual from the well.

Pump Location When Flushing
Install the pump as close to the bottom of the well as possible during the flushing stage. For fractured or very porous rock formations, it may be necessary to move the pump up and down the length of the exposed borehole to assure water movement into the entire well bore.

Pumping Rate When Flushing
Maximize the pumping rate. The greater the volume and velocity of water being pumped, the more effective the flushing will be.

Duration of Flushing
Generally, the longer the flushing time the better. A suggested minimum is to pump until at least 20 casing volumes have discharged from the well (Schnieders - Personal contact).

> Example: A 100-foot deep 5-inch well has a casing volume of 100 gallons. A minimum of 2,000 gallons of water (20 casing volumes times 100 gallons) should be flushed from the well.

Flushing Without Chlorination
In some cases, flushing without further chlorination has been effective in correcting contamination problems. Some local health departments have found that allowing water to discharge from a garden hose continuously for a period of at least 24 hours or more has corrected the contamination problem without the need to treat with chlorine. The hose is discharged into a roadside ditch or into the yard away from any on-site sewage disposal system. Open the sill cock valve all the way during the flushing stage.

Sampling After Flushing
A water sample should be collected from the water supply after the flushing period to determine if the flushing process has corrected the bacterial contamination problem. If coliform bacteria are not present in the water sample analyzed, the flushing may have successfully disinfected the water supply. However, a second water sample is recommended approximately one week later to verify that the bacterial contamination problem has been corrected.

Discharge Water Management
The initial discharge of water from a recently chlorinated well may contain elevated levels of chlorine and chlorination byproducts. Do not run the water into a surface water body. Avoid flushing for long periods if discharge water will flow onto neighboring property or roadways, or otherwise create a nuisance condition.

Chlorine Sources and Characteristics

Although there are several chemical disinfectants that may be used to treat a well, this manual only addresses the use of chlorine, the water supply disinfectant most commonly used.

Chlorine is a bactericidal chemical that destroys or inactivates coliform bacteria that it comes into contact with. Chlorine attempts to disrupt the normal life processes of an organism. This is done by penetrating the cell wall of the organism and upsetting the natural life cycle processes or altering the organism's enzymes. With the cycle so disrupted, the organism either dies or cannot reproduce and the water is made bacteriologically safe (Connell, 1976).

Treatment with a chlorine solution is an essential component of efforts to eliminate microorganisms that have invaded an existing well or have been introduced into a new well during its construction.

Water Supply System Chlorination Objective

To expose all parts of the water system to a chlorine solution of sufficient strength for an adequate time period. The "water system" includes:

1. Water bearing formation around well screen or a rock borehole.
2. Well casing.
3. Pump.
4. Pressure tank.
5. Piping.

Commonly Used Chlorine Sources

Sodium hypochlorite and calcium hypochlorite are the most common sources of chlorine used for disinfection of onsite water supplies. The following provides information on these two chlorine sources:

Sodium Hypochlorite (common household bleach)

- Clear to slightly yellow colored liquid with a distinct chlorine odor.

- Common laundry bleach - 5.25 to 6.0 percent available chlorine, when bottled. Use unscented only. Scented bleaches may leave an odor for extended periods of time, even after the chlorine has been flushed out of the water supply. Do not use bleach products that contain additives such as surfactants, thickeners, stabilizers, and perfumes. These additives may contain hazardous chemicals and should not be used for treating drinking water. Always check product labels to verify product content and use instructions.

- Swimming pool chlorine - 10.0 to 12.0 percent available chlorine. Note that there are types of chlorine other than sodium hypochlorite available for swimming pool use, and these should not be used for treatment of water supplies unless certified as meeting American National Standards Institute (ANSI)/National Sanitation Foundation, Inc. (NSF) Standard 60. Swimming pool chlorine products may contain UV inhibitors, algaecides, or other additives that should not be added to water supplies. Always check product labels to verify product content.

- Higher concentrations of chlorine in sodium hypochlorite solutions are generally not available. Above 15 percent, the stability of hypochlorite solutions is poor, and decomposition and the concurrent formation of chlorate is of concern (Connell, 1996).

- Limited shelf life – Sodium hypochlorite solutions are of an unstable nature due to high rates of available chlorine loss (Pecora, et al., undated). Over a period of one year or less, the amount of available chlorine in the storage container may be reduced by 50 percent or more.

Solutions more than 60 days old should not be counted upon to contain the full amount of available chlorine originally in solution (Driscoll, 1986)(Campbell, et al., 1973).
The stability of hypochlorite solutions is greatly affected by heat, light, pH, initial chlorine concentration, length of storage, and the presence of heavy metal cations (White, 1999)(Connell, 1996). These solutions will deteriorate at various rates, depending upon the specific factors:

1. The higher the concentration, the more rapidly the deterioration.
2. The higher the temperature, the faster the rate of deterioration.
3. The presence of iron, copper, nickel, or cobalt catalyzes the deterioration of hypochlorite. Iron is the worst offender (White, 1999).

Because light and heat accelerate decomposition of sodium hypochlorite solutions, product degradation is less pronounced when containers are stored in a dry, cool, and darkened area or in a container protected from light (AWWA Manual M20 1973). A test kit should be used to check the final chlorine residual in a prepared chlorine solution to assure that you have the intended concentration.

As a General Rule
One gallon of 5.25 percent bleach in 100 gallons of water will make a solution of 500 parts per million (ppm) (Keech, 1983).

Calcium Hypochlorite

- Dry white powder, granules, or tablets.
- 60 to 70 percent available chlorine.
- 12-month shelf life if kept cool and dry.
- If stored wet, looses chlorine rapidly and is corrosive.

As a General Rule
Three-quarters of a pound (about 1 1/2 cups) of granular calcium hypochlorite mixed in 100 gallons of water will make a 500 ppm solution. A chlorine test kit should be used to check the final chlorine residual in a prepared chlorine solution to assure that you have the concentration intended.

Calcium Hypochlorite Tablets
The use of calcium hypochlorite tablets dropped into the top of a well is not recommended as the sole means of disinfecting a well for the following reasons:

1. Tablets are designed to be slow dissolving. This characteristic is not conducive to getting all the available chlorine into the chlorine solution during the desired chlorination time interval.
2. Conditions in a well are not conducive to dissolving chlorine tablets. The water is cold and there is very little agitation or turbulence in the bottom of a well. Tablets are designed for use in applications where the water is warm and water is flowing past the tablets such as in a basket in the recirculation line of a swimming pool.
3. It is difficult to get uniform distribution of chlorine if the tablets are dumped into a well. There will be a strong concentration of chlorine around the tablets, but not in other portions of the well.
4. Tablets poured into the top of a well may lodge on the interior of the pitless adapter or on top of the submersible pump causing corrosion (Franklin Aid, 1987). Cases of severe corrosion of submersible pumps leading to premature failure due to chlorine tablets have been reported in Michigan.
5. The tablets cause high concentrations of chlorine in the bottom of the well, causing chemical interactions with the ground water leading to excessive scaling.

If tablets are to be used as a source of chlorine for a chlorine solution, they must first be broken up and dissolved in a 5 gallon pail or bulk tank. Otherwise, they may remain in the bottom of the well for extended time periods and provide poor distribution of chlorine.

Which is Best, Sodium Hypochlorite or Calcium Hypochlorite?
Current experiences of water well drilling contractors and ground water specialists suggest sodium hypochlorite is more effective (Mansuy, 1999; Schnieders, June, 2001). However, this may be associated with the quality of the ground water in the well being treated rather than with the source of the chlorine itself.

In Michigan, there is an abundance of calcium based materials in both bedrock wells and those finished in glacial deposits. Calcium hypochlorite already has a high concentration of calcium (the white cloudy appearance). At 180 ppm (or approximately 10 grains) of hardness, water is saturated with calcium to the point that it precipitates out of the solution, changing from the dissolved state to a solid state (Schnieders, December 2001).

Introducing a calcium hypochlorite solution into a calcium rich aquifer can cause the formation of a calcium carbonate (hardness) precipitate that may partially plug off the well intake. The plugging can interfere with the distribution of the chlorine solution and possibly reduce the production capabilities of the well (Coombs, 2001; Mansuy, 2001; Schnieders, June 2001; and Smith, 2001). Sodium hypochlorite does not have the tendency to create the precipitate, which may be why it appears to be a more effective disinfectant.

If the calcium carbonate concentration in the ground water is above 100 ppm (mg/l), the use of sodium hypochlorite is recommended instead of calcium hypochlorite (Schnieders, December 2001).

ANSI/NSF Certification
Sodium hypochlorite or calcium hypochlorite that contain other chemicals or additives, such as stabilizers, perfumes, algaecides, or other chemicals that are used for water supply disinfection should be certified that they are in compliance with or surpass the American National Standards Institute/NSF International (ANSI/NSF) Standard 60 for Drinking Water Treatment Chemicals – Health Effects, or an equivalent standard.

Germicidal Efficiency of Chlorine
The major factors affecting the germicidal efficiency of the free chlorine residual process are: chlorine residual concentration, contact time, pH, and water temperature. Increasing the chlorine residual, the contact time, or the water temperature increases the germicidal efficiency. Increasing the pH above 7.5 drastically decreases the germicidal efficiency of free chlorine (White, 1999). Varma and Baumann (Varma, 1959) performed a comprehensive literature review compiling chlorine residuals and contact times needed to kill vegetative bacteria, viruses, and amoebic cysts. Based on this review, a 99.6 to 100 percent kill can be achieved by maintaining a 50 ppm chlorine residual at an approximate pH of 6.4 to 8.6 for 4 to 6 hours at a temperature of 20 to 29^{o}C (68 to 84^{o}F). These concepts and others are discussed in more detail in the following sections.

Form of Chlorine
The form of chlorine that is in a chlorine stock solution is an important factor in how effective the solution is as a disinfectant. Chlorine dissolved in water, regardless of whether sodium hypochlorite or calcium hypochlorite is used as the source of the chlorine, generally exists in two forms, depending on the pH of the water:

- HOCl - hypochlorous acid (biocidal)
- OCl - hypochlorite ion (oxidative)

Hypochlorous acid is the most effective of all the chlorine residual fractions (White, 1999). Hypochlorous acid is 100 times more effective as a disinfectant than the hypochlorite ion (Schnieders, 1998). It is generally thought that the death of bacterial cells results from hypochlorous acid oxidizing essential bacterial enzymes, thereby disrupting the metabolism of the organism. The germicidal efficiency of hypochlorous acid is due to the relative ease with which it can penetrate cells. This penetration is comparable to that of water, and can be attributed to both its modest size (low molecular weight) and its electrical neutrality (absence of an electrical charge) (White, 1999) (Hackett, 1987).

The hypochlorite ion is not as strong an oxidizing agent as hypochlorous acid and the negative charge and the size of the ion impedes its ability to penetrate an organism's cell wall. Hence, the hypochlorite ion is not as effective a disinfectant agent as hypochlorous acid (Hackett, 1987).

pH Effect on Chlorine

Chlorine is a more effective disinfectant at pH levels between 6.0 and 7.0, because hypochlorous acid (the most effective form of chlorine) is maximized at these pH levels (Schnieders, February 1998). Controlling the pH of a chlorine solution increases the effectiveness of the chlorination process. Any attempt to disinfect water with a pH greater than 9 to10 or more will not be very effective (White, 1999) (Connell, 1996).

The pH determines the biocidal effects of chlorine. By controlling the pH of the solution that the chlorine is in, the form of chlorine (hypochlorous acid or hypochlorite ion) can be controlled. If the amount of hypochlorous acid can be maximized by controlling the pH, the effectiveness of the chlorine is significantly increased. The following chart demonstrates how pH affects the form of chlorine.

Effect of pH on Type of Chlorine*		
	Approximate percentage at 32 to 68 degrees F	
pH	Hypochlorous Acid	Hypochlorite Ion
5	100	0
6	97-98	2-3
7	75-83	17-25
7.6	42-63	47-58
8	23-32	68-77
9	3-5	95-97
10	0	100

* From Schnieders, February 1998

Chlorine will raise the pH when added to water. As noted in the chart above, raising the pH reduces the amount of hypochlorous acid present. By increasing the concentration of chlorine, and subsequently raising the pH, the chlorine solution is actually less efficient as a biocide. At higher pH levels, hypochlorite ion is formed, which is the least effective of the two forms of chlorine.

Controlling the pH of the water in the aquifer is not practical. However buffering or pH-altering agents may be used to control pH in the chlorine solution being placed in the well.

Temperature Effect on Chlorine

As temperatures increase, the metabolism rate of microorganisms increases. With the higher metabolic rate, the chlorine is taken into the microbial cell faster, and its bactericidal effect is significantly increased. Therefore, the higher the temperature the more likely the disinfection will produce the desired results.

Steam injection has been used to elevate temperatures in a well and the area surrounding the wellbore as a means of treating for biofouling organisms, and this process may have some application in controlling ground water temperatures (Alford, et al., 1999). However, it is limited to wells with steel casings, and the expense of the treatment generally renders it impractical for use at residential wells.

Interfering Substances Effect on Chlorine

Dirty surfaces and turbid water cannot be effectively treated with chlorine. There may be substances in the water and on surfaces within the well that bind up or use up available chlorine resulting in less chlorine (free chlorine residual) being available to serve as a disinfectant (LeChevallier, et al., 1981) and thereby decreasing the effectiveness of the chlorination process. This binding or using up of chlorine is called chlorine demand. The interfering substances may include:

1. Inorganic matter (sand, silt, clay).
2. Organic matter (synthetic chemicals or biological material).
3. Drilling mud/additives.
4. Dissolved iron and other minerals in the ground water or in the water being used for preparing the chlorine solution.
5. Drill cuttings.

Reaction with reducing ions such as iron, manganese, nitrite, sulfide, and sulfite form the initial chlorine demand. The chlorine reduced to chlorides in these reactions has no disinfection ability. Additional chlorine will then react with ammonia and certain organic compounds to form chloro-organic compounds and chloramines. Combined residuals reach a peak, then decline as more chlorine is added, offering limited disinfection ability. The point at which combined chlorine residuals reach a minimum and a free chlorine residual begins to appear, is known as the breakpoint. Up to this point chlorine demand (dosage minus residual) varies with dosage. Beyond the breakpoint the free chlorine residual increases directly with dosage (Jones, 1979).

The major chlorine demand of concern in well disinfection is not in the water, but on surfaces of the well. Nuisance organisms (organisms able to reproduce in the environment of the well) often produce large quantities of organic matter. The result is a high chlorine demand and sufficient organic energy for the possible propagation of coliform if the water temperature is above 13° C (55.4° F)(Jones, 1979).

Many nuisance organisms are filamentous or slime formers and produce particles that settle to the bottom of the well, along with soil particles, scale, and other debris. It is wise to assume that 20 percent of the chlorine demand exists at the bottom of the well. In wells that have been inadequately disinfected several times, over 90 percent of the chlorine demand may be at the bottom due to settle slimes and other debris loosened in previous disinfection attempts (Jones, 1979).

Only clean surfaces in a well render themselves to effective disinfection with chlorine (Coombs, 2001). Proper development of a newly constructed water supply, proper preparation of an existing water supply, and thorough flushing of a water supply can effectively clean exposed surfaces, remove turbid water, and helps remove most interfering substances.

Chlorine Concentration

Exposure of an unprotected coliform organism to even very low concentrations of chlorine will kill the microorganism. However, the microorganisms may be protected from exposure to the chlorine by protective slimes, cuttings, drilling fluid, scale, etc. These interfering substances, as discussed earlier, will use up available chlorine, thereby allowing the microbes to survive because of insufficient chlorine concentration.

The initial chlorine concentration in the chlorine solution needs to be high enough to assure that there is sufficient chlorine to make up for this “chlorine demand,” and still have a residual of chlorine left to kill the vulnerable microorganisms.

In practice, chlorine concentrations should be kept between 50 and 500 parts per million (ppm) and the standard recommended concentration is 200 ppm (Schnieders, 2001). This allows for enough chlorine to satisfy chlorine demand (interfering substances), and still provide sufficient free available chlorine to disinfect (50 ppm). Exceeding these levels may cause damage to the well or actually reduce the effectiveness of the chlorination process as follows:

1. At higher concentrations of chlorine (in excess of 500 PPM), the corrosivity of the stock solution is significantly increased, creating a potential for damage to metal well components (submersible pumps, check valves, etc.)(Franklin Aid, 1987) **The use of chlorine solutions with chlorine concentrations in excess of 500 ppm is not recommended.**
2. In the presence of higher concentrations of chlorine, the surface of biofilms and mineral scale may be oxidized to form a hard, tight surface (Schnieders, 2001). This sealing of the surface layers then reduces the chance that chlorine will penetrate into the material to make contact with the microorganisms that may exist there.

Contact time

Contact time is the length of time that the chlorine solution is left in the water supply. Sufficient time is needed to allow the residual chlorine to penetrate into biofilms or other materials that may be present, in order to reach any microorganisms that may be present.

During the contact time the chlorine residual should be maintained in the water supply system for 4 to 12 hours (Coombs, 2001). For increased contact time to be most effective, the pH of the chlorine solution in the well must be maintained between 6 and 7 to keep the chlorine in a nonoxidative state (hypochlorous acid). If pH control is not going to be used during periods of increased contact time, use concentrations of chlorine 50 ppm or less (Schnieders, 2001).

The longer the contact time, the more likely the chlorination procedure will be successful, especially if proper concentrations of chlorine are used at controlled pH conditions. Caution should be exercised during periods of extended contact times to minimize corrosive damage to pumps and other well components by controlling levels of pH and using lower concentrations of chlorine.